AIR FORCE
PROPOSAL PREPARATION INSTRUCTIONS

The responsibility for the implementation and management of the Air Force STTR Program is with the Air Force Research Lab, Wright-Patterson Air Force Base, Ohio. The Air Force STTR Program Manager is Mr. Steve Guilfoos, (800) 222-0336. The Air Force Office of Scientific Research is responsible for scientific oversight and administration of Air Force STTRs. All Phase I and Phase II STTR proposals **MUST** be submitted to the following address:

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For general inquires or problems with the electronic submission, contact the DoD Help Desk at 1-866-724-7457 (8am to 5pm EST). For technical questions about the topic during the pre-solicitation period (1 Jan through 28 Feb), contact the Topic Authors listed for each topic on the website. For information on obtaining answers to your technical questions during the formal solicitation period (1 Mar through _ Apr) go to the DTIC SBIR Interactive Technical Information System (SITIS) http://www.acq.osd.mil/sadbu/sbir/solicitations/sitis.htm.

The Air Force STTR Program is a mission-oriented program that integrates the needs and requirements of the Air Force through R&D topics that have military and commercial potential. Information can be found at the following website: http://www.afrl.af.mil/index/htm

Unless otherwise stated in the topic, Phase I will show the concept feasibility and Phase II will produce a prototype or at least show a proof-of-principle.

Phase I period of performance is typically 9 months, not to exceed $100,000.

Phase II period of performance is typically 2 years, not to exceed $500,000.

The solicitation closing dates and times are firm.

Air Force Fast Track
Detailed instructions on the Air Force Fast Track and Phase II proposals will be given out by the awarding Air Force directorate along with the Phase I contracts. The Air Force encourages businesses to consider Fast Track application when they can attract outside funding and the technology is mature enough to be ready for application following successful completion of the Phase II contract. Further information on the STTR Fast Track can be found in Section 4.5 of this solicitation.

Commercial Potential Evidence
An offeror needs to document their Phase I or II proposal's commercial potential as follows: 1) the small business concern's record of commercializing STTR or other research, particularly as reflected in its Company Commercialization Report http://www.dodsbir.net/submission; 2) the existence of second phase funding commitments from private sector or non-SBIR funding sources; 3) the existence of third phase follow-on commitments for the subject of the research and 4) the presence of other indicators of commercial potential of the idea, including the small business' commercialization strategy.

Submission of Final Reports
All final reports will be submitted to the sponsoring agency. Companies **will not** submit final reports directly to DTIC.

Proposal Submission Instructions

ALL PROPOSAL SUBMISSIONS TO THE AIR FORCE MUST BE SUBMITTED ELECTRONICALLY.

It is mandatory that the complete proposal submission -- DoD Proposal Cover Sheet, **ENTIRE** Technical Proposal with any appendices, Cost Proposal, and the Company Commercialization Report -- be submitted electronically through the DoD SBIR/STTR website at http://www.dodsbir.net/submission. Each of these documents is to be submitted separately through the website. Your complete proposal **must** be submitted via the submissions site on or before the April 16, 2003 deadline. A hardcopy **will not** be required. Signatures are not required at proposal submission when you submit your proposal over the Internet. If you have any questions or problems with electronic submission, contact the DoD SBIR/STTR Help Desk at 1-866-724-7457 (8am to 5pm EST).

Acceptable Format for On-Line Submission: All technical proposal files must be in Portable Document Format (PDF) for evaluation purposes. The Technical Proposal should include all graphics and attachments but should not include the Cover Sheet or Company Commercialization Report (as these items are completed separately). Cost Proposal information should be provided by completing the on-line Cost Proposal form.
Technical Proposals should conform to the limitations on margins and number of pages specified in the front section of this DoD solicitation. However, your cost proposal will only count as one page and your Cover Sheet will only count as two, no matter how they print out after being converted. Most proposals will be printed out on black and white printers so make sure all graphics are distinguishable in black and white. It is strongly encouraged that you perform a virus check on each submission to avoid complications or delays in submitting your Technical Proposal. To verify that your proposal has been received, click on the "Check Upload" icon to view your proposal. Typically, your proposal will be uploaded within the hour. However, if your proposal does not appear after an hour, please contact the DoD SBIR/STTR Help Desk.

The Air Force recommends that you complete your submission early, as computer traffic gets heavy near the solicitation closing and slows down the system. **Do not wait until the last minute.** The Air Force will not be responsible for proposals being denied due to servers being "down" or inaccessible. Please assure that your e-mail address listed in your proposal is current and accurate. By the end of April, you will receive an e-mail serving as our acknowledgement that we have received your proposal. The Air Force cannot be responsible for notifying companies that change their mailing address, their e-mail address, or company official after proposal submission.

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Electronic Submission of Proposal

If you have never visited the site before, you must first register your firm and create a password for access (Have your Tax ID handy). Once registered, from the Main Menu:

Select "Prepare/Edit Phase I Cover Sheets" –

1. **Prepare a Cover Sheet.** Add a cover sheet for each proposal you plan to submit. Once you have entered all the necessary cover sheet data and clicked the Save button, the proposal grid will show the cover sheet you have just created. You may edit the cover sheet at any time prior to the close of the solicitation.
2. **Prepare a Cost Proposal.** Use the on-line proposal form by clicking on the dollar sign icon.

3. **Prepare and Upload a Technical Proposal.** Using a word processor, prepare a technical proposal following the instructions and requirements outlined in the solicitation. When you are ready to submit your proposal, click the on-line icon to begin the upload process. You are responsible for virus checking your technical proposal file prior to upload. Any files received with viruses will be deleted immediately.

Select "Prepare/Edit a Company Commercialization Report" –

4. **Prepare a Company Commercialization Report.** Add and/or update sales and investment information on all prior Phase II awards won by your firm.

Once steps 1 through 4 are done, the electronic submission process is complete.

TOPIC NUMBER	ACTIVITY/MAILING ADDRESS	CONTRACTING AUTHORITY
	(Name and number for mailing proposals and for administrative questions)	(For contract questions only)
AF03T001 thru AF03T0	Air Force Research Laboratory AFOSR/PIE Attn: Lt Col James D. Thorne 4015 Wilson Blvd, room 846 Arlington, VA 22203-1954	Richard Pihl (703)696-9728

AIR FORCE 2003 STTR TOPICS

Topic #	Topic Title
AF03T001	Automated Diagnosis of Usability Problems Using Statistical Computational Methods
AF03T002	Detection of Molecular and Biomolecular Species by Surface-Enhanced Raman Scattering
AF03T003	Hadamard Transform Time-of-Flight Mass Spectrometry
AF03T004	Conductive Polymers/Elastomers as Gap Treatment Material for Aircraft
AF03T005	Biomimetic Infrared Sensor Development
AF03T006	Application of Cortical Processing Theory to Acoustical Analysis
AF03T007	Computational Methods for Feedback Controllers for Aerodynamics Flow Applications
AF03T008	Detecting and Extracting Image Similarities, Differences and Target Patterns
AF03T009	Adaptive Sensing and Control for Flexible Transmission in a Turbulent Medium
AF03T010	Shear Stress Sensor Using Shape Memory Films
AF03T011	Storage Efficient Data Mining for High-Speed Data Streams
AF03T012	Control of Supercritical Spray for Gas Turbine Applications
AF03T013	High-Bandwidth High-Resolution Sensor for Hypersonic Flows
AF03T014	Combustion Based Actuator for Flow Control in Transonic Flight Applications
AF03T015	Self-Diagnosis of Damage Criticality of Fibrous Composites Based on Multifunctional Characteristics
AF03T016	Next Generation Hall effect Thruster Concepts
AF03T017	Wireless Technology for Structural-Health Monitoring
AF03T018	Nanocomposites for Carbon Fiber Reinforced Polymer Matrix Composites
AF03T019	High Flux Radical and Ultraviolet (UV) Generation by Atmospheric Pressure Nonequilibrium Plasmas
AF03T020	Zinc Oxide-based Spintronic Devices
AF03T021	Photonic Crystal Chip-scale Optical Networks
AF03T022	Adaptive Artificial Intelligence for Next-Generation Conflict Simulation
AF03T023	Alternating Current (AC) Losses Associated with High Temperature Superconductors
AF03T024	Terahertz Quantum Cascade Lasers
AF03T025	High Average Power Mid-Infrared Semiconductor Lasers
AF03T026	Silicon-Based Quantum Cascade Lasers
AF03T027	Innovative Pulsed Rocket Propulsion Systems for Space Applications

AIR FORCE 2003 STTR TOPIC DESCRIPTIONS

AF03T001 TITLE: Automated Diagnosis of Usability Problems Using Statistical Computational Methods

TECHNOLOGY AREAS: Human Systems

Objective: Develop an automated tool that defines system usability within a classification framework based on user-provided descriptions of usability problems.

Description: Usability analysis is an important tool for the design of complex human-machine systems. This analysis may take place early or late in the system design cycle and usually involves the evaluation of system prototypes. Expert evaluators record usability problems based on what they observe in laboratory-based usability situations. In this process, evaluators usually record what they believe salient about observed usability problems. Even though evaluators often use standardized report forms to ensure inclusion of contextual information, the resulting problem descriptions are more often than not inconsistent, vague, and incomplete. Unfortunately, further analysis and redesign are often performed after a delay in time, by different people, sometimes at a different location or on different prototypes, causing information losses that leave developers to interpret the reports and reconstruct the missing usability information. This poor communication of usability data in the iterative process is partly due to the lack of a classification framework to guide complete and accurate usability problem reporting. The challenge is developing an objective method for capturing the essence of the usability problem description and for locating the problem within a structured taxonomy. The diagnosis of usability problems plays an important role in usability engineering because diagnosis aids description and good description is essential to high quality problem reporting. Usability problems can look similar on the surface but may have different underlying causes; diagnosis helps extract and isolate individual usability problems from the observed usability situations, and diagnosis helps pinpoint the underlying essence of problem causes [1]. Thus, the technical goal of this STTR is to develop an automated diagnosis of usability problem descriptions within a usability classification framework that is based on a statistical contextual analysis of the problem description. Examples of existing usability frameworks include design guidelines [2], heuristics [3], and frameworks based on Don Norman's theory of action model. The User Action Framework is one example of a classification framework based on Norman's model [4]. An example of a statistical computational method that may be used to extract and represent the contextual-usage meaning of words and descriptions is Latent Semantic Analysis (LSA) [5]. The proposed tool will work within a classification framework, identifying the most relevant modes using a contextual statistical method (such as LSA) to code the underlying structure and significance of the problem description.

Phase I: Demonstrate the feasibility of using statistical computational methods (such as LSA) to validate and refine a usability classification framework. Using statistical computational methods and the usability literature, minimize the semantic distance between children and parent nodes and maximize the semantic distance among siblings to ensure the diagnosis decision is objective and clear. Develop an approach for using statistical computational methods to automatically code usability problem descriptions.

Phase II: Develop a semantic analysis tool that automatically takes usability problem descriptions and maps them to nodes within a usability classification framework. This tool should also include the capability to focus the diagnosis even further by interactively asking for specific information to separate out two related but different end nodes.

Dual Use Commercialization Potential: Automated coding of usability problem descriptions within a classification framework can be applied to both military and industry needs. Objective and automated diagnosis of usability problems benefits the design process of large and small computer-based interactive systems by giving literature- and guideline-based recommendations for improvement.

REFERENCES:
1. Cockton, G., & Lavery, D. (1999). A framework for usability problem extraction. In Proceedings of the IFIP Seventh International Conference on Human-Computer Interaction - INTERACT '99 (pp. 344-352). London: IOS Press.

2. Mayhew, D. J. (1992). Principles and guidelines in software user interface design. Englewood Cliffs, NJ: Prentice-Hall.

3. Nielsen, J., & Molich, R. (1990). Heuristic evaluation of user interfaces. In CHI '90 Conference Proceedings (pp. 249-256). New York: ACM Press.

4. Andre, T. S., Hartson, H. R., Belz, S. M., & McCreary, F. A. (2001). The user action framework: A reliable foundation for usability engineering support tools. International Journal of Human-Computer Studies, 54 (1), 107-136.

5. Landauer,T. K., & Psotka, J., (2000). Simulating Text Understanding for Educational Applications with Latent Semantic Analysis: Introduction to LSA. Interactive Learning Environments, 8(2) (pp. 73-86).

KEYWORDS: latent semantic analysis, statistical computational methods, usability problem classification, human-computer interaction, usability framework

AF03T002 TITLE: Detection of Molecular and Biomolecular Species by Surface-Enhanced Raman Scattering

TECHNOLOGY AREAS: Chemical/Bio Defense

Objective: Demonstrate and optimize an optical method for the detection of species utilizing surface-enhanced Raman scattering.

Description: Surface-Enhanced Raman Scattering (SERS) has been demonstrated to improve the detection sensitivity for molecular species by up to fourteen orders of magnitude. This remarkable surface enhancement resulting from plasmon resonances can arise not only when is molecule is close to a metal surface, usually silver, but also when the molecule is in close proximity to clusters of silver atoms. Recent advances in the ability to fabricate and control nanostructures offers the promise to develop techniques and methods to controllably and reproducibly use SERS to quantitatively enhance the detection sensitivity of molecular and biomolecular species.

The goal of exploiting SERS-based detection requires research to make this method reliable, reproducible, and quantitative. The method must also be general so that it can be applied to a wide range of target species. Since Raman scattering does not require the target molecule to fluoresce, SERS inherently possesses great generality. A major goal is to have the analyte bind to the surface-enhancing species in a reproducible way so that a quantitative and reproducible surface enhancement is always obtained. If this is accomplished, SERS-based detection can be advantageously applied to the detection of trace amounts of chemical and biological agents, toxic species, and biological species.

Phase I: Assess candidate surfaces, clusters, or engineered nanostructures for use to enhance Raman scattering for target molecules and biomolecules. Optimize the size, shape, and composition of enhancing metal structure to give maximum SERS signal and maximum reproducibility. Develop analysis methods, spectroscopic configurations, or assays that utilize SERS in a reliable, reproducible, and quantitative detection system.

Phase II: Continue the development of SERS-based sensing methods and fabricate a practical SERS spectrometer or assay system. Perform demonstrations that the new detection method is generally to a wide range of target molecules and biomolecules.

Dual Use Commercialization Potential: Successful development of a SERS-based spectrometer or assay system will lead to commercial development of portable sensors for analysis of trace species including chemical weapons, toxins, biological agents, nucleic acids, proteins, etc.

REFERENCES:
1. S. M. Nie, S. R. Emory, “Probing Single Molecules and Single Nanoparticles by Surface-Enhanced Raman Scattering,” Science (1997) 275, 1102.

2. S. R. Emory, W. E. Haskins, S. M. Nie, “Direct Observation of Size-Dependent Optical Enhancement in Single Metal Nanoparticles,” Journal of the American Chemical Society (1998) 120, 8009.

3. A. Michaels, J. Jiang, L. E. Brus, “Ag Nanocrystal Junctions as the Site for Surface Enhanced Raman Scattering of Single Rhodamine 6G Molecules,” Journal of Physical Chemistry B, (2000) 104, 11965.

4. Y.C. Cao, R. Jin, C. A. Mirkin, “Nanoparticles with Raman Spectroscopic Fingerprints for DNA and RNA Detection,” Science (2002), 297, 1536.

KEYWORDS: Raman scattering, Surface enhancement, Sensors

AF03T003 TITLE: <u>Hadamard Transform Time-of-Flight Mass Spectrometry</u>

TECHNOLOGY AREAS: Chemical/Bio Defense

Objective: Demonstrate and optimize a general, portable, low cost, high duty cycle analytical technique for detecting chemical species based on Hadamard Transform time-of-flight mass spectrometry.

Description: Time-of-flight mass spectrometers (TOF MS) are the simplest and least expensive forms of mass spectrometers. In time-of-flight mass spectroscopy, an ion source is pulsed to create a packet of ions that travels down a flight tube. The flight time of the ions to a detector depends on the velocities of the ions that are directly proportional to their mass-to-charge ratios. In a conventional TOF MS, the system waits for all of the ions in a packet to reach the detector before injecting the next packet of ions. Enhancements in duty cycle and signal to noise ratio can be obtained by modulating the ion beam and deconvolving the ion signals using a method such as a fast Hadamard Transform. This technique will allow the development of mass spectrometers that are low cost, extremely small, portable, and have high data acquisition rates. Such systems would be ideal for the detection of biological and chemical agents, and could be coupled to a wide variety of separation sources.

Phase I: Develop a feasibility concept or innovative design for a prototype mass spectrometer based on Hadamard Transform Time-of-Flight Mass Spectrometry. Optimize the dimension and arrangement of components. Evaluate the performance of the device and assess methods to improve the signal to noise ratio and duty cycle.

Phase II: Construct, demonstrate, and optimize the operation of a prototype miniaturized mass spectrometer based on Hadamard Transform Time-of-Flight Mass Spectrometry. Demonstrate the coupling of the mass spectrometer to several separation methods and ionization sources. Demonstrate the sensitivity and selectivity on prototype molecules that can be used to assess the performance of the instrument for use with biological and chemical agents.

Dual Use Commercialization Potential: Successful development of a Hadamard Transform Time-of-Flight mass spectrometer will lead to commercial development of portable sensors for analysis of trace species including chemical weapons, toxins, biological agents, nucleic acids, proteins, etc.

REFERENCES:
1. A. Brock, N. Rodriquez, R. N. Zare, “Hadamrd Transform Time-of-Flight Mass Spectrometry (HT-TOFMS),” Analytical Chemistry (1998) 70, 3735.

2. A. Brock, N. Rodriquez, R. N. Zare, “Characterization of a Hadamrd Transform Time-of-Flight Mass Spectrometer,” Review of Scientific Instruments (2000) 71, 1306.

KEYWORDS: Hadamard Transform, Mass spectrometry

AF03T004 TITLE: Conductive Polymers/Elastomers as Gap Treatment Material for Aircraft

TECHNOLOGY AREAS: Air Platform, Materials/Processes

Objective: Synthesis, formulation and characterization of conductive elastomers using conductive polymers as gap treatment material for aircraft

Description: To maintain signature characteristics, some low observable (LO) aircraft require continuity of electrical conductivity throughout the outer mold line. Conductive elastomeric sealants are used to maintain conductivity across gaps and seams created at major joint and/or other mating aircraft parts as well as aircraft access panels. One currently commercially available material is polysulfide with nickel-coated graphite filler. Other currently available materials have silver- filled resin systems. These materials have a long cure time and are difficult to repair in the field. As a result, there is a need for new materials that are more durable, have good electrical conductivity, quick cure rates and ease of use in the field for repair. A potential solution for a new gap treatment material is conductive elastomers where the conductive element is an organic conductive polymer rather than metal filler. A conductive polymer would have advantages over metal fillers because of their lighter weight, lower percolation threshold, and improved elasticity.

Phase I: Determine the feasibility of the synthesis and formulation of conductive polymers as conductive elastomers for aircraft gap treatment material.

Phase II: Synthesize, and develop a conductive elastomer formulation as well as perform material characterization of a conductive elastomer gap treatment material formulation using conductive polymers. Formulation methods could range from blending two polymers, mechanical mixing to synthesizing block copolymers. Focus on various dopants that would provide the maximum electrical conductivity.

Dual Use Commercialization Potential: Conductive elastomers can be used as EMI shielding for wiring or enclosures.

REFERENCES:
1. "Crystallization Driven Formation of Conducting Polymer Networks in Polymer Blends" Hopkins, A. R., Reynolds, J. R. Macromolecules, 33, 5221-5226 (2000).

2. "Regiosymmetric Dibutyl-Substituted Poly(3,4-propylenedioxythiophene)s as Highly Electron-Rich Electroactive and Luminescent Polymers" Welsh, D. M., Kloeppner, L. J., Madrigal, L., Pinto, M. R., Schanze, K. S., Abboud, K. A., Powell, D., and Reynolds, J.R. Macromolecules, 35, 6517-6525 (2002).

KEYWORDS: Electrical Conductive Elastomer, Aircraft Gap Treatment, Aircraft Gap Maintenance

AF03T005 TITLE: Biomimetic Infrared Sensor Development

TECHNOLOGY AREAS: Sensors, Electronics, Battlespace

Objective: Demonstrate engineering improvements to non-cooled continuous, real-time IR sensors with the resolution of cryogenic IR sensors.

Description: For years, USAF has invested heavily in understanding how certain biological organisms sense electromagnetic energy in the infrared region of the spectrum. There are a number of papers available (see some below), which describe various advances in both organism mechanism and speed of sensing capability. These biomimetic principals and molecules can be incorporated into a sensitive polymer-based sensor. An array concept can be fabricated that demonstrates imaging in real-time.

With this background in mind, this program should focus on transitioning basic sensor design to more development-intensive programs. Development efforts should focus on established thermal sensor performance enhancing techniques such as thermal isolation. Such concepts are accomplished through a combination of sensor design and chip manufacturing. Thermal specifications should attempt to match or exceed existing cryogenically cooled thermal sensors; such as spacial resolution and speed. Optimum descrimination between target and background is sought.

Phase I: Implement array deposition of polymer/protein pixels. Spatial control and microvolume dispensing are critical to array fabrication success. Develop novel bonding techniques and polymer microfabrication techniques that allow thermal isolation to be maximized for each individual polymer-sensing unit.

Phase II: Continue development of polymer/protein arrays. Improve models and thermal detectivity. Set up a prototype system as a representative sensor platform for a thermal threat simulaion and demonstration.

Dual Use Commercialization Potential: Perform a physical demonstration of the complete system on a representative sensor platform for a range of thermal threat simulations. The successful development of a polymer/protein array chip will lead to applications for air, land and sea unmanned vehicles, especially miniature vehicle designs. This sensing platform will enable sensor deployment in a miniature format because there is no longer a requirement for cryogenic dewars and closed gas cells. This sensing format can also greatly impact civilian activities in law enforcement, fire fighting, and security services.

REFERENCES:
1. Gorbunov V, Fuchigami N, Stone M O, Grace M, Tsukruk V V. (2002) "Biological thermal detection: micromechanical and microthermal properties of biological infrared receptors," Biomacromolecules 3: 106-115.

2. Naik R R, Kirkpatrick S M, and Stone M O (2001) "The thermostability of an alpha-helical coiled-coil protein and its potential use in sensor applications," Biosensors and Bioelectronics 16: 1051-1057.

KEYWORDS: Biomimetic, Polymers, Proteins

AF03T006 TITLE: Application of Cortical Processing Theory to Acoustical Analysis

TECHNOLOGY AREAS: Human Systems

Objective: Develop a computational model of human auditory processing based upon cortical theory and data. Demonstrate its utility to evaluate and/or improve systems for speech communication and automated recognition of spectro-temporal patterns

Description: Current systems for audio processing and communication, including Automatic Speech Recognition (ASR) systems, are vastly inferior to human auditory performance. They fail to emulate human hearing in the general task of segregating and organizing dynamic acoustic inputs into multiple streams (e.g., multiple talkers). Human hearing is more tolerant of reverberant sound, better able to recognize regularities in timbre and temporal patterns, and less susceptible to interference from non-random background sound.

During the last decade, much has been learned about the physiology, organization, and functions of the auditory cortex. But computational approaches based upon this knowledge have yet to be fully exploited. A basic goal of this research is to formulate a computational model consistent with theory and data regarding cortical processes as well as with cochlear mechanics and early auditory stages. The model should be computationally and experimentally testable. It should provide a quantitative characterization of such "non-intensive" phenomena as the grouping and streaming of sound sequences, and the audibility of spectro-temporal patterns

This computational modeling approach should lead to significant and wide-ranging applications involving the analysis, synthesis, and identification of acoustic signals, medical and industrial diagnostics, speech recognition, and the design and characterization of communication channels. One particular interest is the enhancement of ASR performance in multitalker, noisy, or reverberant environments. Another is the development of improved metrics for speech intelligibility. Currently, the most widely used metrics – the Articulation Index , and the Speech Transmission Index – are based upon restrictive assumptions that require prior specification of the noise conditions affecting intelligibility. These applications will require strong collaboration to link auditory science with speech technology engineering.

Phase I: Design and develop a prototype computational model of human audition to include a representation of higher-order sensory/perceptual mechanisms associated with cortical processing. Demonstrate the model's ability to integrate key neurophysiological and psychoacoustical findings. Identify and define an approach for its application to technical problems in speech processing, auditory displays, or communication systems.

Phase II: Develop and validate the model. Demonstrate applications to technical problems in speech processing, auditory displays, or communication systems. Produce and demonstrate portable technology for these applications.

Dual Use Commercialization Potential: A computational model and the associated technology for Department of Defense applications is equally useful for commercial applications, which may include speech intelligibility assessment, virtual audio displays, ASR systems, medical and industrial diagnostics.

REFERENCES:
1. Hawkins, H. L. & McMullen, T. A. (Eds.) Auditory Computation. [Handbook of Auditory Research, Vol. 6, edited by A.N. Popper & R. R. Fay.] New York: Springer, 1995.

2. Gilkey, R. H. & Anderson, T. R. (Eds.) Binaural and Spatial Hearing in Real and Virtual Environments. Mawah, New Jersey: L. Erlbaum 1997. ISBN 0-8058-1654-2.

3. Greenberg, S. & Slaney, M. (Eds.) Computational Models of Auditory Function. NATO Science Series, IOS Press: Amsterdam, 2001. ISBN 90-5199-457-5

4. DeCharms, R. C., Blake, D. T., & Merzenich, M. M. (1998) Optimizing sound features for cortical neurons. Science, 280, 1439-1443.

5. Deprieux, D. A., et al. (2001) Spectro-temporal response field characterization with dynamic ripples in ferret primary auditory cortex. J. Neurophysiol. 85, 1220-1234. [And see references therein.]

KEYWORDS: Computational Audition, Speech Intelligibility, Bioacoustics

AF03T007 TITLE: <u>Computational Methods for Feedback Controllers for Aerodynamics Flow Applications</u>

TECHNOLOGY AREAS: Air Platform, Information Systems

Objective: Development of a computational toolbox for the design of feedback controllers for a variety of real-world applications in aerodynamic flow control.

Description: Practical methodologies for the design of reliable, robust feedback controllers for distributed parameter systems are essential for the successful implementation of closed-loop aerodynamic flow control. Existing simulation codes for the Navier-Stokes equations have various difficulties when used as a basis for controller design. Direct numerical simulation codes that capture detailed aspects of the flow are unsuitable for real-time computation and for control design because of the enormous number of states. Although they may be used in conjunction with model reduction techniques, difficulties often exist in model reduction for control design with respect to capturing essential features of the closed-loop dynamics. The controllers arising from the methodology should tolerate changing flow conditions such as Reynolds number, Mach number, and flow angularity, as well as be implementable in real time. Sensing and actuation are typically restricted to the boundary of the computational domain. Due to such limitations, estimators will likely be necessary.

Methods based on model reduction prior to control law design and on control law design before order reduction should be compared to ensure an adequate understanding of the effects of order reduction. In addition to the toolbox for control law design, a plan for the transition of the method to experimental implementation on general configurations is required.

Phase I: Demonstrate a prototype of the toolbox for a variety of aerodynamic applications. Include a variety of computational domains, flow conditions, boundary conditions, sensors and actuators.

Phase II: Develop the toolbox into a commercializable product.

Dual Use Commercialization Potential: Successful development of closed loop aerodynamic flow control will lead to a physical demonstration of the complete system on air vehicle platforms that are applicable for a range of subsonic and/or transonic flight conditions and vehicle orientations. Potential applications include air, land and sea vehicles.

REFERENCES:
1. E. Lavretsky and N. Hovakimyan, Reconstruction of Continuous-Time Dynamics Using Delayed Outputs and Feedforward Neural Networks, IEEE Transactions on Automatic Control, 2002, submitted.

2. J.A. Atwell and B.B. King, Reduced Order Controllers for Spatially Distributed Systems via Proper Orthogonal Decomposition, SIAM Journal on Scientific Computing, 1997, submitted.

3. J.A. Burns, B.B. King and D. Rubio, On the Design of Feedback Controllers for a Convecting Fluid Flow via Reduced Order Modeling, Proceedings of the 1999 IEEE CCA/CACSD, Kohala Coast, Hawaii, August 1999, 1157 – 1162.

4. B. Bamieh and M. Dahleh, Energy Amplicfication in Channel Flows with Stochastic Excitation, Physical Fluids 13[11] page 3258 –3269, Nov. 2001

KEYWORDS: Feedback control, distributed parameter systems, flow control

AF03T008 TITLE: Detecting and Extracting Image Similarities, Differences and Target Patterns

TECHNOLOGY AREAS: Sensors, Electronics, Battlespace

Objective: Demonstrate synergistic integration of methodologies for detecting changes or similarities of sequences of images and extracting-recognizing patterns or targets.

Description: A common problem in image data mining and pattern recognition is the development of robust techniques able to determine the similarities, or changes (differences) between two images. Several efforts have attempted to develop functions for determining the degree to which two images differ from each other. More specifically, the most common measure is a tree matching process according to a similarity criterion that uses a tree depth function to define the distance in similarity. These approaches use shape based similarity measure, especially on simple geometric objects at a local level. Other methods use Euclidean, Housedorf, or Machalanobis distances to define the degree of similarity mainly on shape-based images or objects. In the case where a computer-based system has to visually observe two images, or a sequence of images from the same or different sensors, it makes a decision about them, (for instance if they are the same, or similar (what degree of similarity), or different, and what type of patterns are contained). This is a difficult task especially when the decision has to be made in real-time and under noisy conditions. Thus, the topic here is the synergistic integration of methods for automatically detecting, extracting, and recognizing changes, similarities in target patterns in sequences of images. The proposed methodology can be on sequences of real images, radar images, thermal images, infrared (IR) images and fusion of different types of images.

Phase I: Develop a software tool methodology (proof of concept) as the result of the integration of different methods capable of automatically detecting and extracting changes, similarities, and target patterns from sequences of images. The tool methodology will be able to except different types of image sensory data. Final report and demonstration, of the software tool performance is required.

Phase II: Design and develop a real-time system prototype capable of automatically detecting, extracting, and recognizing changes, similarities and target patterns of video, or sequences of image data, from different sensory devices. Prototype system must have the ability of fusing these types of sensory data and make more effective decisions and choices related with the selected target pattern.

Dual Use Commercialization Potential: Design an staggered pin grid array-very large scale integration (SPGA-VLSI) version of the system prototype able to perform on speed vehicle, such as aircraft, unmanned vehicles, etc.

REFERENCES:
1. [Bour] N.Bourbakis, Emulating human visual perception for measuring differences in images using an SPN graph approach, IEEE T-SMC, 32,2,191-201, 2002.

2. [Bourba] N.Bourbakis Low resolution target tracking and recognition from a sequence of images, Int. Journal AIT, vol.11,No.4, 2002.

3. [Gir] B. Girod, "The Information Theoretical Significance of Spatial and Temporal Masking in Video Signals", Proc. of the SPIE Human Vision, Visual Processing, and Digital Display, vol. 1077, pp. 178–187, 1989.

4. [Sag] J. A. Saghri, P. S. Cheatham, and A. Habibi, "Image Quality Measure Based on Human Visual System Model", Optical Engineering,Vol. 28, No. 7, July 1989.

KEYWORDS: Data Mining, Image Differences, Image Similarities, Target Pattern Detection

AF03T009 TITLE: Adaptive Sensing and Control for Flexible Transmission in a Turbulent Medium

TECHNOLOGY AREAS: Information Systems

Objective: Demonstrate free-space transmission to measure ambient conditions and adjust power level, divergence, encoding, and coherence.

Description: There is a need for computation, modeling and adaptive feedback mechanisms to improve transmission of signals and energy across the troposphere or other medium. A new concept in free-space transmission brings in the ability to measure ambient conditions and to adjust parameters in real time. Such operating parameters include optical power level, beam divergence, encoding, and coherence. Enhanced statistical and physical modeling of the transmission channel is needed to design appropriate feedback and interactive mechanisms for optimization of the communication link and network. The same approach could result in greater delivery of power on target in directed energy applications.

Line-of-sight communication through optical links has strong advantages in massive bandwidth capability, directionality, and built-in covertness but contends with the challenge of the refractive and dispersive effects of the turbulent atmospheric medium. Better understanding of the physical essence of turbulence will also permit countermeasures that improve delivery of high-power laser energy. Once sensing data on the transmission channel is available to the entire system, control of the key model parameters can utilized through mechanisms such as refocusing, adaptive reflecting elements, power adjustment, and exploitation of coherence properties

The control of the active optical elements, deformable mirrors, micro-electrical/mechanical elements (MEM's), and liquid crystal spatial light modulators (LC-SLM), in the transceiving optical link, requires new laser communication system architectures and protocols.
Key elements for high-rate laser-based transmission are:
(a) Real-time measurement of the communication channel and transceiver performance metrics.
(b) Multiplexing of channel and link performance information into data streams (including video and hyperspectral imagery).
(c) De-multiplexing of channel and system performance metrics from the received video data stream.
(d) Feedback control of active optical elements/channel encoding using embedded performance metric.

Metrics of interest in the propagation of laser beams through the atmosphere must continuously be calibrated and updated. One such statistic is the variance of intensity of the optical field at various planes along a propagation path. Custom integrated imaging sensors should collect and compute characteristics of the received optical signal after channel propagation: position of the beam centroid, spread and size, scintillation (signal fading) and the characteristic spatial correlation distance. Such sensors will also allow the anticipation of channel fading and facilitate "on-the-fly" channel encoding.

Preference will be given to proposals that show evidence of mathematical depth as well as hands-on familiarity with applications of essential importance to the Air Force, and that convey a viable road-map for technical insertion of discoveries and accomplishments.

Phase I: Conduct a study of operating parameters that may be used to optimize electromagnetic transmission through the troposphere in both low-power (communications) and high-power (directed energy) case. Explore methods and approaches for dynamic control of parameters. Define a system architecture based on the study findings. Outline a plan to be pursued in Phase II.

Phase II: Refine and document the stochastic modeling/metric adaptation methodology developed in Phase I.
Design, construct, and test a prototype intelligent link or directed energy delivery system that makes full use of the gathered and disseminated metric data. Validate the improvement in channel performance made possible under the prototype with customized sensing chips and control procedures.

Dual Use Commercialization Potential: Refine the design for specific application such as commercial system for quick installation/temporary link, or military field application.

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KEYWORDS: Adaptive Optics, Phase screen generation, Monte Carlo simulation

AF03T010 TITLE: Shear Stress Sensor Using Shape Memory Films

TECHNOLOGY AREAS: Materials/Processes, Sensors, Electronics, Battlespace

Objective: Develop a low profile, simple, accurate, localized, responsive wall shear stress sensor for monitoring the state of external boundary layers on aircraft and missiles.

Description: There is a need for sub-millimeter sized sensors capable of measuring localized shear stress on a solid body in a fluid flow. Recent developments in the growth of single crystal films of martensitic (shape memory) materials, grown, for example by molecular beam epitaxy make it possible to exploit this class of materials for sensor applications. Typically, the martensitic phase is extremely sensitive to shear stress. A rearrangement of the variants of martensite directly affects other properties of the film such as electrical resistance, and in some cases (e.g. ferromagnetic shape memory films) magnetic properties. In single crystal form these properties are expected to be cooperative, giving a large response. In the martensitic alloy Ni2MnGa first principles density functional theory studies have demonstrated an unusually flat energy landscape as a function of the c/a ratio. Concepts for sensors in unreleased or partly released films are sought.

Concepts for patterning the films to create high density arrays of sensors can be proposed, especially concepts that are suitable for the extraction of characteristics of turbulent boundary layer flow. To avoid perturbing the flow field, nanometer variability of film step height is desirable. Design of patterning strategies might make use of recent advances in the understanding of the martensitic transformation in single crystal films.

Phase I: Develop a method to grow single crystal films of a martensitic material that show a high degree of sensitivity to shear stress and that demonstrate sensing capability. Activities involving the prediction of optimal epitaxial orientations and patterning strategies and the development of a methodology for the growth of single crystal films of martensitic material suitable for shear stress sensing. The researchers should become familiar with Air Force applications in which shear stress sensing is important.

Phase II: Develop the processing for integration with microelectronics for automated sensing. Test and calibrate films, for instance, in shock tubes and wind tunnel conditions. Determine optimal arrays of sensors for extracting important characteristics of turbulent boundary layer flow.

Dual Use Commercialization Potential: A wide variety of sensing devices are an essential part of commercial and military aerodynamic vehicles. With sufficiently high sensitivity, such a system could also detect motion of other objects from a stationary location. The ability to record the details of shear stress profiles (perhaps coupled with more standard pressure sensors) could potentially be used to identify physical and dynamical characteristics of the object whose motion is being sensed. These sensor arrays can be integrated with control strategies that allow for the control of bulk vehicle motion or boundary layers: Simulations presented in the literature have predicted large drag reduction by active control of wall turbulence, but these remain to be successfully implemented. A sensor of this type could also provide a crucial test of models of turbulence such as large eddy simulation models.

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KEYWORDS: Martensitic materials, turbulence control, wall shear stress, molecular beam epitaxy

AF03T011 TITLE: Storage Efficient Data Mining for High-Speed Data Streams

TECHNOLOGY AREAS: Information Systems

Objective: Produce data mining algorithms that are sensitive to the limited storage requirements of a given facility.

Description: Current knowledge discovery systems extract inference rules relating various attributes of data sets stored in large databases. These raw data sets are obtained off-line, and batch processing is usually effected. However, in many applications of current interest it is not adequate for the user to store the entire data stream as it arrives. By doing so, the user could fill up its storage resources with non-informative data sets, while important information would be lost when the storage media is full. For example, everyday retail chains record millions of transactions, popular Web sites log millions of hits, and computer intrusion detection systems process billions of packets or other form of audit information. Only a small fraction of these items would prove worth of further inspection by an inference engine, but the user does not know which ones. Hence, current practice is to store all items and filter them later, which produces storage overload. Data compression certainly alleviates the problem, but ultimately one needs a principled strategy to filter high-speed streams, taking into account the storage capacity. Desired research under this topic falls into two areas: (1) Algorithms that incorporate new data items into current inference engines, without recording the data item and occupying valuable space; (2) Algorithms that decide on-line to store or not an incoming data item based on a cursory examination of its contents. It is expected that the best solutions will incorporate elements of both. It is also expected the proposed scheme to be able to cope with bursty data streams, where the time interval between arrivals of item sets vary considerably.

Phase I: Investigate principled approaches for performing data mining under storage constraints. Develop performance metrics taking into account storage constraints, accuracy and computational performance. Select a domain area (retail transactions, intrusion detection, news streams, etc.) and produce a proof-of-concept demonstration validating the proposed scheme.

Phase II: Develop and demonstrate a prototype system in a realistic environment for a selected domain area. Conduct extensive testing to prove feasibility over a large range of operational conditions.

Dual Use Commercialization Potential: The prototype developed in Phase II could be productized, and put into use in a broad range of military and civilian applications where storage media is limited. Examples include telecommunication companies recording patterns of user calls, financial institutions recording patterns of transactions, computer security facilities storing audit information, etc.

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KEYWORDS: Data Mining, limited data storage capacity, limited storage media

AF03T012 TITLE: Control of Supercritical Spray for Gas Turbine Applications

TECHNOLOGY AREAS: Air Platform

Objective: Formulate novel atomization methods for transcritical and supercritical propellant injection.

Description: Given recent successes in control of ultra-fine sprays and development of advanced numerical tools, control of transcritical and supercritical spray combustion in realistic gas turbine combustors is now an achievable goal. The use of intelligent fuel injectors capable of producing ultra-fine spray offers the potential of enhanced performance and combustion stability in gas turbine engine combustors operating at elevated pressure and in which fuel spray is in the transcritical and/or supercritical state. Laboratory experiments have demonstrated controlled atomization can yield reduced emissions and stable combustion. These effects could result in reduced fuel consumption, augmented specific thrust, and increased control authority for future gas turbine engine combustion systems. The purpose of this program is to integrate development of novel fuel injection methods with advanced numerical simulation tools, which will be required to fully understand supercritical spray behavior and realize the full benefits of improved fuel atomization and mixing.

Development and implementation of passive and active control strategies based on control of atomization quality, without change in injector geometry and gas flow rates, is necessary for effectively and efficiently controlling the supercritical spray combustion over a range of flight conditions and vehicle attitudes. A method for modeling the transition from subcritical to supercritical two-phase combustion must be developed that will aid in understanding the fuel injection and on combustor performance. This is a major challenge since for example, as the pressure increases new phenomena appear that complicate the physics of spray development. The associated increase in Reynolds number and real gas behavior in the domain can cause thermodynamic and physical properties to vary by many orders of magnitude in a very small region. In particular, as the thermodynamic conditions reach critical conditions, classical spray atomization (due to liquid jet breakup caused by dynamic forces and surface tension effects) no longer occurs. Instead, molecular diffusion processes occur prior to atomization, liquid sheet begins to vaporize to form a continuous fluid, and classical droplet formation diminishes significantly. Liquid undergoes transient heat-up and therefore, need not reach its critical state immediately upon entering a supercritical environment. Fuel-air mixing and flame stabilization under supercritical conditions are also substantially different from what has been observed in conventional low-pressure combustion systems. The models can be developed using simulations and/or physical experiments. The ultimate objective of the project is the creation of novel fuel injection methods and numerical approaches that will enable control of supercritical spray combustion.

Phase I: Develop or access candidate fuel injectors capable of providing controlled variation of spray mean droplet diameter from 1 ƒÝm to 100 ƒÝm. Integrate candidate fuel injectors in high-pressure combustion environment to study atomization of hydrocarbon fuel atomization and mixing as a function of combustor pressure, flow rates, and air-to-fuel ratios. Determine combustor benefits due to ultra-fine controlled atomization. Initiate development of advanced simulation tools capable of modeling transient two-phase spray to include dense spray breakup with real gas effects. Develop a test plan for Phase II.

Phase II: Develop measurement techniques to quantify the effect of atomization on supercritical spray combustion. Continue development of advanced simulation tools to include real gas effects, to account for diffusion terms due to pressure and temperature gradients, and more general transport coefficients. Perform a physical demonstration of the complete fuel injection system on a representative turbine engine combustor platform for a range of transcritical and supercritical conditions. Demonstrate combustion performance enhancements and reduced emissions in a simulated combustion environment. Produce and test the performance of a prototype combustor with intelligent fuel injector based on the results of the Phase I and Phase II studies. Validate the advanced simulation model using the experimental supercritical spray combustion data under realistic conditions.

Dual Use Commercialization Potential: Successful research will produce novel fuel injection concepts and advanced simulation tools that can be used to improve aerospace and terrestrial propulsion systems and for power production. For example, in addition to aerospace applications, novel fuel injector would be attractive for land based gas turbines and diesel engines, including propulsion for military tanks and trucks.

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KEYWORDS: Droplet spray atomization supercritical

AF03T013 TITLE: <u>High-Bandwidth High-Resolution Sensor for Hypersonic Flows</u>

TECHNOLOGY AREAS: Air Platform

Objective: Develop a robust high-bandwidth high-resolution sensor for measurement of hypersonic flow phenomena.

Description: Accurate measurement and characterization of unsteady phenomena in hypersonic flows is critical for the design of efficient air-breathing vehicles for rapid economical global and space access. Examples of such phenomena include instability waves, which precede transition from laminar to turbulent flow in the boundary layer, fluctuations within the turbulent boundary layer and unsteady conditions resulting from dynamic shock motion. The combined effects of high velocities, thin boundary layers and extreme expansion of the working gas in typical ground test facilities leads to test conditions where pressure fluctuations may have frequencies of hundreds of kilohertz while having amplitudes less than one torr. An added complexity is that the instrumentation must be sufficiently rugged to survive the severe transient loads of facility start-up and occasional off-design operation. Traditional sensors such as hot-wires and piezo-electric transducers suffer from a trade-off between bandwidth, sensitivity and ruggedness.

Given these considerations, there is a clear opportunity to improve upon the current state-of-the-art in hypersonic flow instrumentation. The purpose of this effort is to develop a robust, high-bandwidth, high-resolution sensor for measurement of unsteady phenomena in hypersonic flows.

The ideal sensor/system should be capable of measuring fluctuations of 0.01% of mean quantity measured in flow conditions typical of a “cold flow” hypersonic ground test facility with minimum bandwidth of one Megahertz and a maximum probe volume one the order of one cubic millimeter. Sensor ruggedness and survivability should be emphasized in the development. Later stages of development may extend sensor design to operation in high-enthalpy hypersonic ground test facilities. Radio-frequency and electromagnetic interference (RFI / EMI) tolerance and turn-key operation are highly desirable.

Phase I: Assess candidate phenomena for measurement and measurement technique. Demonstrate measurement capability in bench-top simulation of unsteady hypersonic flow. Begin efforts for sensor ruggedization. Formulate plan for Phase II development.

Phase II: Continue development sensor/measurement scheme. Finalize sensor ruggedization. Demonstrate measurement capability in “cold flow” hypersonic ground test conditions.

Dual Use Commercialization Potential: Sensor development will be extended to application in high-enthalpy hypersonic ground-test facilities. Potential dual-use applications, dependent on final sensor size, bandwidth, and sensitivity, include application in lower speed flow regimes and possible bio-medical applications.

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KEYWORDS: Hypersonic, Sensor, Ground-Test

AF03T014 TITLE: <u>Combustion Based Actuator for Flow Control in Transonic Flight Applications</u>

TECHNOLOGY AREAS: Air Platform

Objective: Demonstrate an integrated combustion-based flow control actuator, for use on aircraft, with sufficient control authority for transonic flow applications.

Description: Many recent successes have demonstrated the ability of pulsed or synthetic jets to control aerodynamic flows for aircraft and engines, including separation and circulation control, jet vectoring, and mixing enhancement. While the effectiveness of pulsed flow control approaches has been demonstrated, most work has focused on low speed demonstrations for which the development of actuator technologies has been relatively straightforward. High-speed applications will require a new generation of robust, durable actuators. Recently, a new class of actuators has been demonstrated which may provide advances in actuator authority (e.g. high blowing momentum coefficient and high jet exit velocity), variable operating frequency, and simplified integration. These actuators are based on a combustion cycle, with the combusting gas providing more than an order of magnitude increase in the momentum flux to the flow, as compared with the premixed gases alone. These actuators utilize the high energy density of fuel to provide the control authority necessary for challenging flow control applications in the transonic flow regime. These devices also offer the advantage of compact size (on order of a cubic centimeter combustion chamber), rapid rise time of the pulse, and variable operating frequency.

Significant research is required for further development and commercialization of these devices. For aircraft integration, logistics fuels (e.g. JP-8) must be utilized. This will require either advancements in atomization and fuel-air mixing on the scale of these devices, or alternative approaches utilizing fuel reforming to convert logistics fuels into light gaseous hydrocarbons. Application of these devices to large areas on flight vehicles implies a need to address batch fabrication or mass-formation of these devices. Alternatives to distributed spark sources must also be explored. Ideally, the manufacturing process should provide for integration of electronics, plumbing and control valves, to avoid the need for individually interconnecting the devices. Robust fabrication materials will be required to survive the harsh flight environment, high temperatures and products of combustion.

Development of the flow control device must be guied by the ultimate applications to ensure appropriate scaling. Candidate applications may include transonic circulation control, jet vectoring, or separation control. The effort should culminate in the demonstration of the actuator technology on a relevant flow phenomena. This demonstration may be accomplished in an appropriate wind tunnel facility or on a representative aircraft or engine. Pilot tests leading to this demonstration should address the critical operating parameters of the combustion based actuator, such as exit velocities, momentum flux, exit temperatures, and durability. Because a single device may not be suitable for both scale-model and full-scale testing, aerodynamic benefits may be addressed in the preliminary development by simulation of the device in either computational or experimental tests.

All aspects of the development, integration, and application of the actuator—including durability, batch-fabrication methods, cost, integrated electronics and plumbing, conformal application of the actuator on aerodynamic vehicles, aerodynamic benefits of the targeted flow control application, and planned demonstrations addressing transonic applications—will be considered in the evaluation process and should be addressed in the proposal.

Phase I: Determine technical feasibility of candidate actuator concepts through initial demonstrations of a prototype combustion-based actuator. Provide initial demonstrations of critical components and manufacturing processes to provide a means of scaling and integrating the actuator concept, including the batch manufacturing process, flight-rated fuel reforming, and demonstration of the operation of multiple actuators. Characterize actuator operation parameters including exit velocities, momentum flux and temperature of the actuator. Develop a fabrication, implementation and test plan for Phase II.

Phase II: Address or demonstrate integrated valves and electronic controls for operation of the actuators, the range of achievable actuator frequencies, and the durability of all proposed materials to be used in the manufacture of the combustion-based actuators. Determine system benefits for actuator applications on a targeted air vehicle platform. Develop a suitable manufacturing process for batch fabrication or mass forming actuators with integrated electronics and plumbing. Demonstrate conformal actuators for application on aerodynamic surfaces. Develop an implementation plan for Phase III.

Dual Use Commercialization Potential: Demonstrate combustion based actuator in a realistic flight environment, addressing all integration issues required to use aircraft fuel, integrated electronics, flight control integration, materials and conformal mounting on vehicle, survivability in harsh environments for extended duration use. Perform a physical demonstration of the complete system on a representative air vehicle platform for a range flight conditions, including transonic flight speeds.

Successful development of a combustion-based actuator will lead to applications for air, land and sea vehicles. Drag reduction and shock control on commercial transport aircraft will reduce fuel consumption. A robust actuator with sufficient control authority using high energy density sources will enable multiple flow control applications.

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KEYWORDS: Flow Control, Combustion, Actuators

AF03T015 TITLE: Self-Diagnosis of Damage Criticality of Fibrous Composites Based on Multifunctional Characteristics

TECHNOLOGY AREAS: Materials/Processes

Objective: Demonstrate methods and models to perform self-diagnosis of damage to fiber-reinforced composite structures for aerospace applications.

Description: Advanced fiber composites with polymer matrices are widely used in aerospace structures due to their superior load-carrying performance, greater damage tolerance and lower weight than their metal counterparts. However, because of relatively poor penetration resistance, local damage can be inflicted easily upon polymer composites, particularly with brittle graphite fiber reinforcement, during their manufacture, transport, and final use involving abusive contact or foreign object impact (such as birds, hails or meteorites). The damage occurs in a complex form of fiber breakage, matrix/interface cracking and delamination of the plies and its criticality cannot be easily determined due to the subsurface nature. Extensive research efforts involving a variety of experimental methods have been underway to detect the location, extent, and type of damage that may have occurred in sufficient detail and thereby to assess the health of composite structures. One good example is the incorporation of embedded or surface mounted sensors into composite structures. However, the method presents a number of problems such as complicated processing, stress concentration caused by the presence of sizable sensors, and reliability issue of connections. In view of these limitations, new efforts were made to utilize electrically conductive nature of built-in reinforcements of graphite fibers in composites. Recent investigations indicated that a composite ply or laminate consisting of aligned graphite fibers embedded in non-conductive polymer matrix exhibits a finite electrical resistance associated with the resistance of graphite fibers. It was also observed that the dependence of electrical resistance of composites on mechanical strain is in turn affected by the fiber volume fraction. Under mechanical load, each fiber breakage was found to interrupt the current flow thereby increasing the electrical resistance of the composites along the fiber direction. In other words, the electrical resistance of the composites becomes a measure of mechanical damage of fiber reinforcements. These results render a new possibility of practical technique for in-situ damage detection and strain sensing in fiber-reinforced composite structures relying on "multi-functional" characteristics of constituent materials. In addition to fiber reinforcement, the polymer matrix may be modified or engineered to have specific functional properties desirable for damage detection. In order to achieve the objective of in-situ self-diagnosis of damage in composites, the criticality of damage in various forms should be related to the electrical, magnetic, spectroscopic or other functional properties of composites. This relationship needs to be established within a broader context including the variation of fiber orientation, ply construction and laminate lay-up of composites. Insensitivity or adaptability to temperature extremes is also desirable. At the same time, it is necessary to couple physical network model of composites to the mechanical model of damage and thereby to formulate predictive tools for the estimation of damage criticality of composite structures.

Phase I: Identify constituent material systems which have specific functional properties desirable for damage detection of resulting composites. Relate the criticality of damage in various forms to the selected functional properties of composites within a broader context including the variation of fiber orientation, ply construction and laminate lay-up. Develop experimental hardware for monitoring of damage initiation and evolution based on the selected functional properties of composites. The test panels shall be manufactured in a production mode according to composite manufacturer's process specification in order to simulate a practical composite structure in field. Formulate predictive tools for the estimation of damage criticality of composites by relating physical network model of composites to the mechanical model of damage. Verify the formulated models experimentally.

Phase II: Demonstrate the feasibility of using experimental methods and accompanying theoretical models developed in Phase I to monitor damage initiation and evolution and to perform in-situ self-diagnosis of damage criticality for the fiber-reinforced composite structures in the field. Design and manufacture sub-scale aerospace composite structures. Verification articles shall be damaged or manufactured with known flaws similar to those in large composite structures. The accuracy of the damage detection system shall be verified by the comparison with state-of-art destructive or non-destructive inspection techniques. Characterize the performance of developed predictive tools over a range of structural scaling and operating conditions including elevated temperatures.

Dual Use Commercialization Potential: Successful development of experimental methods and accompanying theoretical models, which can perform in-situ self-diagnosis of damage criticality of fiber-reinforced composite structures, will lead to extensive dual-use applications in the manufacture, maintenance, and repair of space, air, sea and land vehicles made of advanced fibrous composites. Self-diagnosis capability will grant early warning of the damage evolution reaching a critical level in composite structures during the use, thereby allowing greater survivability of the vehicles.

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KEYWORDS: Fiber composites, aerospace structures, health monitoring: multifunctional behavior.

AF03T016 TITLE: Next Generation Hall effect Thruster Concepts

TECHNOLOGY AREAS: Space Platforms

Objective: Develop/validate concepts to increase lifetimes of Hall effect thrusters, and investigate low power and mass electron sources.

Description: Hall effect thrusters are an increasingly popular choice for spacecraft propulsion applications for both macroscale and miniaturized satellites. The major operational deficiencies in the state-of-the-art Hall thrusters are the short lifetimes (less than 1000 hours) in conjunction with high erosion rates of the insulation material, and the lack of low power, low mass, electron generation for propellant ionization and/or neutralization. Innovative concepts that would reduce the erosion rate of these thrusters (and thus increase lifetime) would be beneficial to Hall thruster systems, particularly for small Hall thrusters. Possible areas of exploration include (but are not limited to), the use of low erosion insulator materials and methods of reducing the beam divergence of the Hall thruster. The state-of-the-art techniques for electron generation (such as hollow cathodes operating on the same propellant as the thruster) do not scale down in mass, power, and propellant consumption as readily as the miniaturized thrusters themselves. Novel concepts leading to the low power, low mass, and "propellantless" electron sources that can operate for durations on par with the thruster itself, are sought. A strong emphasis should be placed on the analysis and assessment of the concept, and the experimental validation of the design.

Phase I: Research and assess the feasibility of proposed methods to extend the lifetimes of Hall effect thrusters, and/or novel electron sources.

Phase II: Apply the results of Phase I to the design, fabrication, experimental validation, and optimization of a prototype extended lifetime Hall effect thruster system and/or novel electron sources. Deliver to Air Force for further testing and evaluation. This system could be applied to any spacecraft using Hall effect thrusters, thereby increasing mission capability and profitability. Thus, the outlook for commercialization appears strong.

Dual Use Commercialization Potential: Develop and qualify an extended lifetime Hall effect thruster system and/or electron source for military and commercial satellite marketplaces.

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KEYWORDS: Electric Propulsion; Hall thruster, lifetime, erosion, Electron Sources.

AF03T017 TITLE: Wireless Technology for Structural-Health Monitoring

TECHNOLOGY AREAS: Materials/Processes, Sensors, Electronics, Battlespace

Objective: Develop technology for a self-powered, self-contained structural-health sensor patch to estimate structural damage and transmit results.

Description: Structural-health monitoring (SHM) is one of the most important keys to improving the reliability of aerospace-weapons systems. A major obstacle to adding SHM sensors to existing systems is the wiring required to connect them to monitoring computers. Wireless technology can eliminate the wiring, but requires a local power source. Moreover, the best damage-evaluating algorithms require active sensors that excite the structure and then measure its response, and these sensors require significantly more power than those that only monitor. The ideal SHM sensor, which does not yet exist, is a small (the smaller, the better) "slap-on" device capable of harvesting the power it needs from the energy present in the ambient environment to excite the structure, monitor its response, compute its health, and then transmit this information to a central computer for decision-making. The enabling technology then rests on the issue of power harvesting, or the ability to power an active wireless monitoring system (AWMS) with the available ambient energy. A truly wireless SHM sensor will perform the functions of harvesting and storing energy, exciting, sensing, computing, and telemetry. Computing at the sensor is desirable because in general it takes less power to compute and then transmit the results than to transmit the raw data and then compute. Additionally, it is desirable for the AWMS to be remotely programmable.

Phase I: Effort will be focused on developing a prototype system that incorporates the functions mentioned above into a single chip of relatively small size. The prototype should be demonstrated on an aircraft panel, or some other representative Air Force structural system, to illustrate its effectiveness.

Phase II: Effort will be focused on the full-scale development of the technology for practical applications to weapon systems, and will include sub-element and component testing. This testing will serve to validate the application of the technology to a variety of structural components of existing aerospace-weapon systems.

Dual Use Commercialization Potential: Technology can be applied to both rotary-wing and fixed-wing military aircraft as well as satellite systems. Automotive and civil-aviation industries, among others, will benefit from this technology.

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KEYWORDS: Sensors, telemetry, structural-health monitoring, diagnosis

AF03T018 TITLE: Nanocomposites for Carbon Fiber Reinforced Polymer Matrix Composites

TECHNOLOGY AREAS: Air Platform, Materials/Processes

Objective: Develop new nanocomposite concepts that can impact and improve the performance of carbon fiber reinforced polymer matrix composites.

Description: Nanocomposites, composites that are reinforced with well dispersed nano-particulates, including exfoliated clay sheets, carbon nanotubes, metallic, metallic oxide and siloxane nanoparticles, have been shown to improve the performance of polymers in many areas such as stiffness, heat distortion temperature, control of thermal coefficient of expansion, corrosion resistance in extreme environments etc. Many of these nanocomposites however are not directly relevant to the carbon fiber reinforced polymer matrix composites technology. This topic is specifically targeting nanocomposite concepts that are relevant to improving carbon fiber reinforced polymer matrix composites. Areas of improvement include, but are not necessarily limited to, higher temperature performance capability, mechanical performance, damage resistance, extreme environment corrosion resistance, and improved dimensional control. The targets of impact can be at various levels of composite technology, such as matrix, fiber, ply, or laminate.

The proposed material concept can be a substitute of a constituent of the current composite technology or a replacement technology that provides equivalent or better performance characteristics in comparison to composite laminate technology. The proposed research must clearly delineate how the proposed concept is relevant to the carbon fiber reinforced composite technology and articulate scientifically convincing arguments of the expected target of improvement from the proposed concept. Processing viability is not a primary consideration in this topic, but a scientifically feasible processing scheme for the proposed concept that will lead to the fabrication of structures for applications must be considered and offered.

Phase I: Assess the proposed concept and illustrate its relevance to carbon fiber reinforced polymer matrix composite technology and demonstrate the potential improvement in the relevant performance properties.

Phase II: Continue development of the concept and demonstrate the improvement of performance over current composite technology.

Dual Use Commercialization Potential: Successful demonstration of the concept will lead to applications of the technology in civilian aerospace industry, automotive industry and other transportation industry such as train, bus and metro systems and in sports industry such as safety equipment and sport equipment items.

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KEYWORDS: Carbon Fiber Reinforced Polymer Matrix Composites, Nanocomposites

AF03T019 TITLE: High Flux Radical and Ultraviolet (UV) Generation by Atmospheric Pressure Nonequilibrium Plasmas.

TECHNOLOGY AREAS: Materials/Processes

Objective: Demonstrate the operation of an atmospheric or near-atmospheric pressure plasma for the generation of UV radiation.

Description: Atmospheric pressure high flux plasma sources have been developed for a wide variety of industrial applications(1). Usually the large rise in gas temperature, even in many nonthermal plasmas, limits usage to materials processing of high temperature materials. Atmospheric or near-atmospheric-pressure gas discharge sources, which can operate at high reduced electric field (E/n, where E is the plasma electric field and n is the gas density) have the advantage of efficiently generating UV and radicals, while holding the rise in gas temperature to 200-300 K. These plasma sources primarily utilize corona discharge(2), dielectric barrier discharge(3), or short-pulsed dc micro-cavity discharge(4). Currently, these types of discharges have not been optimized for high flux generation and control of gas temperature rise. Recent advances in high repetition rate, high speed, high voltage pulsed power conditioning can be applied to either corona discharge, or dielectric barrier discharges, allowing the production of high fluxes of UV radiation and atomic/molecular radicals sufficient for surface property modification and decontamination of temperature sensitive materials. The availability of such plasma sources will find its use in many military and commercial applications, such as: adhesion and wettability modification of polymers(1); plasma polymerization, including biocompatible and composite materials growth(1, 5); low temperature rapid sterilization; and surface contamination cleaning. The main objective of this research task is to demonstrate the scalability of high E/n atmospheric or near atmospheric pressure plasma source for the production of high flux UV and radical sources while maintaining the gas temperature rise to less than 100 K from the ambient gas temperature. The demonstration of the scalability will require measurements of the radical and UV flux, along with the gas temperature rise in the plasma device. Specific gas-mixture plasmas, such as, argon/oxygen, argon/water vapor or argon/hydrogen may be used to quantify both the UV and the radical flux (or at least the absolute radical density), and the gas temperature rise from Doppler broadening or from the ground electronic state rotational temperature measurements. Other gas mixture plasmas suitable for biomaterial compatible polymerization can also be used to demonstrate the commercial potential of this type of plasma source.

Phase I: Design and demonstrate the operation of a high repetition rate, short pulse duration high E/n atmospheric or near atmospheric pressure plasma source which can be scaled up for the generation of high flux of UV and radicals. A high voltage, high speed, high repetition rate pulse power supply will be required and its impedance should be matched to the plasma source as much as possible. During phase I, the design concept should be validated by quantitative measurements of radical and/or UV flux and the gas temperature rise for the corresponding discharge conditions.

Phase II: Demonstrate the scaling of the plasma source for high flux of UV radiation and O, H, or OH radical production using a high repetition rate, high E/n atmospheric or near atmospheric pressure plasma source. Validate the concept of low temperature oxidation, and sterilization or wettability change of polymers. Quantify the efficiency and the scalability of the radical production by absolute number density or flux measurement. Also, quantify the gas temperature rise from Doppler broadening or from the ground electronic state rotational temperature measurements.

Dual Use Commercialization Potential: Successful research will produce a novel plasma source that can be used for aerospace and biomedical temperature sensitive materials surface properties modification, low temperature decontamination and sterilization, replacing the use of ethylene oxide, formaldehyde and other carcinogenic materials. Sterilization of food and medical instruments market alone may exceed $100M per year. Commercial market for other applications is expected to be at least $10-20M per year.

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KEYWORDS: Gas discharge, Plasma, UV radiation, Atomic radical production

AF03T020 TITLE: Zinc Oxide-based Spintronic Devices

TECHNOLOGY AREAS: Materials/Processes

Objective: Demonstrate ZnO spintronic devices including laser and resonant tunneling diodes with high switching speeds and frequencies.

Description: Recent theoretical predictions of room temperature ferromagnetism in ZnO make the promise of semiconductor spintronics achievable. [1] This, together with recent advances in the growth of high quality ZnO epitaxial layers together with the
successful p-doping of ZnO with Nitrogen [2] open up new opportunities for the design and development wide bandgap p-n diode light emitters [3]. With wide bandgap MgZnO alloy barrier layers (MgO bandgap 7.8 eV and ZnO bandgap ~3.38 eV) sandwiching nanoscale ZnO layers, quantum-well, deep ultraviolet lasers are now made practical. The inclusion of Manganese (Mn) magnetic ions in ZnO provides an additional dimension to device expectations in the MgO-ZnO material system. The Mn-doped system [4] can be expected to display very large spin splitting of the energy levels due to the large s-p-d exchange interaction between the band electrons/holes (with their spins) and the Mn 2+ spins. The generation of "mega-gauss" local fields due to the Mn 2+ spin alignments with modest "kilogauss" external magnetic fields implies that this materials system is ripe for exploration of spintronics and optoelectronics device applications after an initial phase of epitaxial growth, doping and characterization experiments. Fixed external magnetic fields for each device could be provided by layered permanent magnet materials, applied monolithically during fabrication process.

Phase I: Phase I tasks would include feasibility demonstration of the epitaxial growth, doping and the optical and magnetic characterization of layered Mn-doped, p-type MgZnO/ZnO heterostructures and the carrier transport properties of these layered heterostructures, and/or the theoretical modeling of their properties to help demonstrate feasibility. Spintronics applications would require a focus on confining free carriers in the layers containing Mn-doping, which, e.g., could be based on the following double heterostructure system: MgZnO/ZnO/MgZnO, doped everywhere p-type with N, and Mn-doped only within the confined ZnO nanostructural layer.

Phase II: A Phase II effort would consist of design/growth and characterization of spintronics device applications in the quantum nanostructures based on the MgZnO/ZnO material system. Envisaged are lasers with spin-selective transitions for polarized radiation and the modulation of such polarization with external bias and magnetic field modulation (case of devices with variable external magnetic fields) and spintronic transistors through spin-selective tunneling in resonant tunneling devices. Similar arguments can be made concerning the mechanism of conduction and its control in more conventional spintronic diodes and triodes, although insertion of a gate electrode may be necessary in the latter to insure complete control over carrier depletion and modulation.

Dual Use Commercialization Potential: A Phase III effort would be devoted to exploitation and commercialization, perhaps in the electronics industry, of any prototype spintronic devices demonstrated or developed under Phase II.

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KEYWORDS: Spintronics, p-type ZnO, Nitrogen Doping, Manganese Doping, Resonant Tunneling Diodes.

AF03T021 TITLE: <u>Photonic Crystal Chip-scale Optical Networks</u>

TECHNOLOGY AREAS: Sensors, Electronics, Battlespace

Objective: Develop chip scale all-optical components for optical communications and networking utilizing photonic crystals and demonstrating a variety of functions including guiding, switching, splitting, modulating, coupling and filtering.

Description: Advances in integrated circuit manufacturing techniques have allowed for the miniaturization of devices on rapidly decreasing scales to the submicron or nanometer regime. At these dimensions, where feature sizes are less than the wavelength of light, it is possible to produce optical materials and devices that allow for unique photonic control and manipulation. A new class of optical devices based on submicron periodic structures has emerged and is referred to as photonic crystals (PhC) or photonic band gap devices (PBGs). (These micro and nanostructured materials exhibit a dielectric constant which is periodically modulated on a length scale comparable to the desired wavelength of light). At the same time, there have been substantial efforts in designing all-optical components, such as all-optical switches and waveguides, for optical communications and networking. There is a need for a unified platform to integrate all these components in a single substrate. Photonic crystals are potential breakthrough approach for such all-optical circuits. Preliminary research indicates that these devices will be capable of performing a wide variety of functions such as switching, splitting, modulation, and filtering.

Future battlefields systems will exploit highly sophisticated guided wave and wireless communications networks connecting command and control with dense arrays of intelligent sensors, compact reconnaissance platforms and unmanned and manned military assets. These environments will need ultracompact, lightweight, low-power, low-cost optical sources, antenna transmitters and detectors. Such technologies in turn require advances in design of ultracompact microphotonic structures, with design and engineering of the electromagnetic properties of materials at the scales comparable to the wavelength of light. Successful completion of this program will aid the development of high quality, robust, photonic circuits to serve as an integrating medium for optical components and networks and to perform basic, on-chip functions such as signal conditioning and signal processing.

Phase I: Clearly demonstrate the feasibility of photonic crystals for chip-scale device implementation through confinement or manipulation of light in waveguides, modulators, lasers, grating-based filters, ring resonators, couplers and/or photonic crystals. Demonstrate multifunctional nanophotonic devices combining switching, modulation, routing, pulse reshaping and regeneration on a single substrate. Identify performance parameters and relevance to advanced optical networks, optical interconnects, and wavelength division multiplexing needs to be addressed. This phase of the work focuses on photonic crystal passive and active components, chip-scale integration, and tools for designing the all-optical circuits. Research may include the development of efficient simulation tools for the analysis of the photonic crystal structures and using these tools to design electromagnetic modes with desired properties, development of fabrication and processing tools and methods (such as quantum dot incorporation) to make the optimized photonic crystal devices and guides, and the development of new methods to efficiently couple the entire photonic crystal integrated circuit to an outside fiber, and exploitation of the semiconductor industry infrastructure to develop low cost, light weight, and low power consumption nanophotonic systems which could include monolithically integration with high-speed digital and analog electronics.

Phase II: Build upon Phase I work and demonstration of the utility of the photonic crystals as building blocks for chip scale all optical networks. Perform appropriate analysis and modeling, grow and /or process the material or structure, fabricate the devices and test their performance. The research should be an integrated effort for providing the platform for making all-optical circuits for optical communications and information processing using photonic crystals. Different optical devices (cavities, lasers, detectors, etc.) in these all-optical circuits would be connected by photonic crystal waveguides. Efficient coupling of light between these waveguides and individual devices as well as that between these waveguides and outside fibers would be developed. New tools for fabricating these photonic crystal circuits over large areas would be addressed.

Dual Use Commercialization Potential: This work is expected to permit the monolithic integration of microelectronic and photonic circuits and will serve as an enabling technology for future active and passive nanophotonic components. The concept should pave the way for the development of a whole new class of nanophotonic devices and all optical chip-scale components with the potential for significantly impacting optical computing and the telecom and integrated sensing industries. Some of the anticipated benefits are smaller physical dimensions, ultra-dense integrated packaging, and reduced manufacturing costs through easily automated, high volume production; and increases in performance factors and lower power. Applications for these nanophotonic elements are seen in the field of quiet communications, enhanced responsivity optoelectronic transduction, photovoltaic energy conversion, remote smart sensors, chemical and biological sensors, parallel computing, optical logic, energy storage, and special coatings.

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KEYWORDS: Nanostructures, photonic crystal, photonic bandgap, nanophotonics, optical nanodevices, integration, waveguides, optical switching, modulators, lasers, wavelength division multiplexing, WDM, PBG, chip scale optical networks

AF03T022 TITLE: Adaptive Artificial Intelligence for Next-Generation Conflict Simulation

TECHNOLOGY AREAS: Information Systems

Objective: To create a truly challenging Artificial Intelligence (A.I.) "opponent" in a state-of-the-art computer-based wargame.

Description: Our national leadership's planning for war is naturally focused on the objective of securing a better state of peace. For over a century, wargames have been used to guide national decision-makers in war. The First-Generation wargames of the Prussian General Staff were chess-like in their focus on the mechanics of strategy and movement. World War II saw the emergence of more detailed modeling to accurately portray the attrition factors impacting forces in combat.1 We may consider this "Second-Generation" wargaming. Unfortunately, such wargames continue to be used because some believe they give "good enough" answers regarding alternative battle plans. Unfortunately, such models that only address movement and attrition ignore critical variables that have become increasingly decisive as the emphasis in conflicts shifts toward minimizing casualties on all sides. Innovative wargame algorithms are needed that account for such effects as information warfare and strategic attacks to paralyze an enemy's infrastructure.

Furthermore, innovative and adaptive A.l. is necessary to serve as a challenging and truly unbiased opponent in such wargames. Far too often, the "red" and "blue" teams for combat simulations are chosen from among individuals having very similar military background and training. This creates a natural bias in employed strategies that can often completely miss real-world strategies that would in fact be employed by individuals with decidedly different cultural and military backgrounds. A.l. can compensate for this by inserting cultural and social idiosyncrasies for different parts of our world. Furthermore, the A.l. can actively "observe" the tactics and strategy types employed by a given opponent and thereby "learn" what concepts work best to defeat its human adversary. This forces the human adversary to avoid behavior that is too predictable and forces him/her to constantly rethink approaches to given military problems. Overall, this creates an environment optimized for true learning on the part of the person playing the wargaming. It maximizes chances for conceiving a strategy that will truly succeed with minimum casualties against a complex and intelligent foe.

Phase I: Investigate the simulation science and adaptable artificial intelligence necessary to comprehensively model armed conflict from the opening of hostilities through the reestablishment of peace. The combat simulation software that emerges must accurately model all belligerents and neutrals as systems, including all decisive human factors and the various decision loops whose lengths depend upon the level of command. These novel methods should be conceptually demonstrated through a computer-based simulation of a historically well-documented strategic or operational conflict.

Phase II: A full computer-based, artificially intelligent Next-Generation combat simulation system will be created. First, the previously-selected conflict will be modeled in its entirety to benchmark the accuracy of the code. 'Then, this software will be extended to model the Gulf War to incorporate modem combat technology.

Dual Use Commercialization Potential: The future commercial market is potentially enormous. Initially, there will be a modest potential for the sale of campaign planning software to the US's closest allies. A somewhat larger market will include, US, allied and friendly professional military education programs, both in residence and distance-learning. A still larger market could include US and international college defense studies programs. Finally, the largest market will be direct sales to consumers. Domestic spending on recreational software exceeded spending on movie tickets in 1996, exceeding US$25B worldwide in 1997. Several individual conflict simulation titles have grossed over a billion dollars in worldwide sales. Academic use and/or commercial success of a civilian version of this project would have the added benefit of educating voters regarding a realistic picture of the capabilities and limitations of armed force.

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KEYWORDS: Combat Simulation, Artificial Intelligence, Game Theory

AF03T023 TITLE: <u>Alternating Current (AC) Losses Associated with High Temperature Superconductors</u>

TECHNOLOGY AREAS: Sensors, Electronics, Battlespace

Objective: Determine or minimize the AC losses experienced by high-temperature superconductors in rotating machinery and transformers.

Description: Early attempts at building a synchronous generator with both low-temperature superconducting rotor field windings and armature windings, i.e., an all-cryogenic generator, failed because the ac losses in large- diameter superconducting filaments were excessive. Technological developments for NbTi wire enabled ultra-fine filaments to be processed in a resistive CuNi matrix that helped minimize the ac loss for the fully penetrated field in the active length of a superconducting armature winding. The million-filament NbTi conductors were used by Alsthom to wind an armature for an all-cryogenic superconducting generator. Success was limited by processing difficulty in manufacturing the conductor in long lengths without physical bridging of the densely-packed NbTi filaments, which caused increased ac losses and cooling requirements for the armature near 4.2K.

The Air Force is currently pursuing the development of HTS generators that dramatically reduce the cooling requirements for operation. The principal focus is to provide lightweight, compact, high-power sources for airborne applications. Lightweight aircraft generators are typically very high speed (6,000 to 20,000 rpm), resulting in a high-frequency armature (several hundred Hz). Commercial BiSrCaCuO superconductors that can operate at 20-35 K may not be ideal for a superconducting rotor field winding due to excessive ac losses in the pure silver matrix.

Introduction of epitaxially-grown YBaCuO superconductors on metallic substrates with interleaved buffers has inspired a re-examination of superconducting armatures and calculation of ac loss over a wide parameter space. Initial calculations indicate that practical superconducting armatures may be designed with low ac loss at 77K.

Determination of the ac losses is critical to development of the HTS conductor, as well as of the HTS generator. Development of low-ac-loss conductors is essential to making armature windings viable and an all-cryogenic-generator approach feasible, as opposed to a superconducting-rotor-only approach. This requires that ac losses be identified and minimized in the conductor by either improved material or conductor configurations.

Phase I: Identify and determine ac losses expected in the candidate superconducting wire(s). This may consider the whole HTS conductor or a portion thereof (such as improved substrate material). Modeling efforts of the expected ac losses also are acceptable. Develop an approach for minimizing ac loss in these wires, as well as a methodology for implementing the approach in long-wire development and production. Prepare an implementation and test plan for Phase II.

Phase II: For material work, fabricate a short-length conductor. Test to verify ac losses and the ability of the material to bend for windings. Improve the performance of the conductor with respect to ac loss minimization and extend the processing to longer lengths of material. Demonstrate the ability of the conductor to be used in armature windings. For modeling efforts, extend the model to allow for differing material and varying conductor configurations. Determine optimum performance of the conductor with respect to ac loss minimization for several applications to demonstrate versatility of the program.

Dual Use Commercialization Potential: Establish a manufacturing capability for armature-quality superconducting wire or form a commercial partnership with such a manufacturer to whom the technology can be transferred. Determination and reduction of AC losses in coated conductors will have direct applicability to production of compact, efficient generators, motors and transformers that may be used commercially and by the military services.

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KEYWORDS: Superconductors, cryogenics, alternating current losses

AF03T024 TITLE: Terahertz Quantum Cascade Lasers

TECHNOLOGY AREAS: Sensors, Electronics, Battlespace

Objective: Development of quantum cascade lasers for operation in the range between 0.3 THz to 10 THz for use in communications, sensing, and near object analysis.

Description: The terahertz frequency range (0.3 - 10 THz) is one of the last frontiers in the electromagnetic spectrum. The lower microwave and millimeter wave frequency regions have been and continue to be exploited for numerous wireless communication and radar applications, whereas the optical and infrared frequencies are being used for high bandwidth data transmission and some niche applications, including night vision. However, terahertz applications have been slow to develop, mainly due to the lack of miniature, reliable sources, detectors and related passive components. The region offers the potential for a number of applications including space-based and short-range terrestrial or near earth communications, atmospheric sensing, collision avoidance for aircraft and ground vehicles, and near object observation and spectroscopy (specifically, detection of trace gas molecules contained in the effluent of high explosives). To realize these applications innovative approaches are needed leading to the development, fabrication, and operation of coherent terahertz sources. Based on recent developments the quantum cascade laser structure is such an approach.

In conventional semiconductor lasers, light is generated by the radiative recombination of conduction band electrons with valence band holes across the bandgap of the active material; in contrast, electrons in a quantum-cascade laser propagate through a potential staircase of coupled quantum wells, where the conduction band is split by quantum confinement into a number of distinct subbands. By choice of layer thickness and applied electric field, lifetimes and tunnelling probabilities of each level are engineered in order to obtain population inversion between two sub-bands in a series of identical repeat units. Injector/collector structures connect these active regions, allowing electrical transport through injection of carriers into the upper laser level, and extraction of carriers from the lower laser level. The radiation frequency is determined by the energy spacing of the lasing sub-bands, allowing in principle operation at arbitrarily long wavelengths. The quantum-cascade scheme is seen as the preferred choice in many attempts to fabricate a terahertz semiconductor laser. The goals of this effort will be quantum cascade laser devices and device concepts that will deliver coherent radiation at potentially milliwatt power level, ultimately coupled efficiently in THz circuits, guided wave structures and antennas.

Phase I: Clearly demonstrate the feasibility of the proposed approach. Define the quantum cascade laser (QCL) device that will deliver up to sufficient power of coherent radiation at specified frequencies in the THz regime. Demonstrate modeling and simulation of the band structure and characteristics of QCLs for specific wavelengths of interest; thin film growth and materials characterization of the Group Ill-V or Group IV based laser structures; fabrication and measurements of the optical spectra and tunability of QCLs; and design of associated gratings, waveguides or thermal management structures. Tunable QCLs would be of interest.

Phase II: Build upon Phase 1 work and demonstration of system components and implementation of a working device. Perform appropriate analysis and modeling, grow the material and/or structure, fabricate the quantum cascade laser device and test its performance. Improvements in emission power, tunability, and higher laser operating temperatures would also be performed in Phase II using novel packaging, heat-sinking, and power management methods.

Dual Use Commercialization Potential: Terahertz technology has selected potential applications. Covert communication on the battlefield or in space, chemical agent detection, atmospheric environment sensing, near object detection, material imaging will benefit from new technology in this part of the electromagnetic spectrum.

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KEYWORDS: Terahertz devices, terahertz emitters, terahertz lasers, terahertz sources, submillimeter, spaced-based communications, atmospheric sensing, quantum well, quantum cascade laser, chemical sensors, explosives, infrared spectroscopy, environmental sensing

AF03T025 TITLE: <u>High Average Power Mid-Infrared Semiconductor Lasers</u>

TECHNOLOGY AREAS: Materials/Processes

Objective: Develop and supply reliable, mid-infrared wavelength (2 to 5 micrometers) semiconductor laser sources with several watts or higher average power and other convenient operating characteristics, suitable for DOD and commercial needs.

Description: The mid-infrared (IR) portion of the optical spectrum has very important technological relevance to both defense and commercial applications. Laser sources of sufficient power would have applications to heat seeking missile countermeasures and to spectroscopic detection and monitoring of low-level gaseous species, for explosive and chemical agent detection, and for remote sensing of emissions for intelligence purposes. . Recent advances in the growth of compound semiconductors containing antimony, which emit light in the spectral band between 2 and 5 micrometers, have demonstrated several watts of CW or quasi-CW power. Various structures containing antimony compounds either alone or in combination, from room temperature electrically injected diodes to optically pumped low temperature lasers have demonstrated potential for multi-watt average power operation.

Phase I: Research materials, processing, and device concepts that could lead to reliable semiconductor lasers in the 2 to 5 micrometer output wavelength range, at average powers of several watts or higher. Perform key preliminary experiments to document viability of concepts chosen for later development. Identify trade-offs and optimum choices between power output, wavelength range, operating temperature, and laser lifetimes.

Phase II: Develop and demonstrate prototype lasers for commercialization in phase III. Research specific military and commercial requirements for mid-infrared lasers to match prototypes developed with military and commercial market needs.

Dual Use Commercialization Potential: Very significant civilian applications would result from a focused development and marketing of the mid-infrared lasers described above. These include pollution and safety monitoring, process control, human and animal health monitoring, and detection of atmospheric turbulence. In particular, the widespread availability of a multi-watt source at the ubiquitous carbon-hydrogen vibrational stretch resonance, at about 3.4 micrometers, may create many important unanticipated products and applications.

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KEYWORDS: Mid-infrared lasers, Semiconductor lasers, Infrared sensing. Remote sensing

AF03T026 TITLE: <u>Silicon-Based Quantum Cascade Lasers</u>

TECHNOLOGY AREAS: Sensors, Electronics, Battlespace

Objective: Demonstrate manufacturable SiGe quantum cascade lasers that operate within desired wavelengths and temperatures.

Description: Quantum Cascade Lasers (QCLs) use intersubband transitions to provide laser power at wavelengths previously inaccessible to conventional semiconductor lasers. [I] Quantum cascade lasers operating in the THz frequency range are needed for remote sensing of chemical agents and detection of trace gases, as well as for combustion diagnostics, LIDAR, and pollution monitoring. [2] At higher powers they would also be useful for free-space communications. The benefits of a silicon based laser are: low-cost manufacturability, reliability, and monolithic opto-electronic integration of Si or SiGe electronic integrated circuits with electrically actuated photonic devices. At present, the Si-based QCL is very near to realization, judging from the experimental LWJR SiGe quantum cascade emitter results at several laboratories around the world. [3] Theory and experiment suggest lasing within the 10 to 100 um range at temperatures of 77 to 300K. Test instrumentation for the 30 to 100 micron range is fairly demanding but well known.

An essential part of this QCL is the virtual substrate (VS) consisting of a relaxed buffer of SiGe fabricated on a silicon wafer. The VS allows strain balance across the coherently strained Multiple Quantum Well (MQW) stack, removing the critical stack-thickness constraint, and allowing multi-micron-thick stacks as desired for long waves. The purpose of this program is to realize manufacturable high-performance SiGe QCLs on VS.

Phase I: Define a manufacturable SiGe/Si process and procure appropriate VSs. Design, construct, and electro-optically test a prototype Sick/Si QCL, anywhere within 10-100 micron, operating at 77K, plus associated testing at lower temperatures if needed. Modify and improve the laser in a second QCL device that reveals a technological path to QCL optimization. Develop an implementation and test plan for Phase II.

Phase II: Using knowledge from each result, construct a series of QCL devices in order to optimize the laser's operating temperature, efficiency, and power output. Demonstrate on-chip integration with electronics. Demonstrate fabrication of a laser array-on-chip. Identify a technique for laser-and-detector integration on chip. Make a manufacturable prototype.

Dual Use Commercialization Potential: Successful development will lead to applications in military and commercial "illuminated" sensor systems; chem./bio sensing, and environmental pollution detection Spectroscopic real-time sensing is a unique benefit that would be accomplished by fabricating a multi-spectral array of QCLs on one chip for simultaneous multi-color emissions. Active imaging and communication are other dual use applications.

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KEYWORDS: Semiconductor laser, Silicon Germanium, Quantum Cascade, Long wave infrared, terrahertz

AF03T027 TITLE: Innovative Pulsed Rocket Propulsion Systems for Space Applications

TECHNOLOGY AREAS: Space Platforms

Objective: Develop pulsed rocket propulsion systems demonstrating superior performance in space to conventional steady state systems.

Description: To the extent that they approach constant volume-limit combustion, pulsed propulsion systems offer theoretical advantages over conventional constant pressure systems, such as potentially increased specific impulse and reduced pumping requirements. Achieving these advantages in practice, however, will require clever scientific and engineering approaches. For example, much attention has recently been given to achieving pulsed propulsion through detonations, but detonations are not always reliably achieved. Relatively little attention has been given to alternative approaches to achieve rapid combustion that do not require detonations. Furthermore, attention needs to be given to ways to maximize the performance achieved for a given method of ignition. Examples of the latter would include developing optimal mixture ratio distributions or developing nozzle technology for pulsed, under-expanded systems in space. In many cases the basic mechanisms or characteristic rates may not be clearly known for likely spacecraft propellants under the low ambient pressure conditions of space, and will have to be determined. Innovative approaches of all kinds, not limited to the examples given above, are sought which will result in distinctive advantages over conventional steady state propulsion systems.

Phase I: Assess the feasibility of a pulsed propulsion concept.

Phase II: Design, fabricate, and demonstrate the operation of the concept as a working prototype. Conduct the necessary scientific investigations to support the development of the prototype. Deliver to the Air Force for further testing and evaluation. This system could be applied various space systems, thereby increasing mission capability and profitability. Thus, the outlook for commercialization appears to be strong.

Dual Use Commercialization Potential: Develop a pulsed propulsion system for military and commercial space marketplaces.

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KEYWORDS: Pulsed propulsion, detonations, pulsed combustion, thrusters